Review on the proceeding of automatic seedlings classification by computer vision

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Abstract: The classification of seedlings is important to ensure the viability of seedlings after transplantation and is acknowledged as a key factor in forestation and environmental improvement. Based on numerous papers on automatic seedling classification (ASC), the seedling grading theory, traditional grading methods, the background and the proceeding of ASC techniques are described. The automation of the measurement of seedling morphological characteristics by photoelectric meters and computer vision is studied, and the automatic methods of the current grading systems are described respectively. And the further researches on ASC by computer vision are proposed.

Keywords: Seedlings classification; Automation; Morphological characteristic; Computer vision

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Introduction

The efficiency of afforestation is determined by the quality of the planting seedlings. Billions of seedlings are produced from nursery stock each year to support afforestation. Thus ensuring the quality of seedlings is the most important task in a nursery, the grading of seedlings and selecting of optimum ones for transplantation is very important. The resistance of seedlings to diseases and pests and their viability after transplanting can be increased by seedling selection.

In the traditional grading, seedlings are manually graded by inspectors on grading tables or conveyor belts. They visually examine individual seedling by dimension and appearance. Manual grading requires inspectors to unceasingly concentrate their attention and is subjective and subject to man-made errors. It is not feasible for inspectors to inspect every seedling or to grade seedlings into more than two classes. Timely processing is also important to reduce the stress of root exposure. The manual method cannot meet the requirement of modern seedling production. With the development of modern technologies, many new measuring methods have been successfully applied to the measurement of seedling features, and many studies have been carried out on automatic grading method of seedlings. As a result of improvements made in digital imaging and computer vision technologies made in the last 20 years, researchers have made attempts to apply these technologies to automatic seedling classification (ASC).

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Criterion of seedling grading

The quality of a seedling can be evaluated by its morphological features and physiological attributes.

The morphological features of a seedling include:

(a) The characteristics of a seedling above ground. These include the height and weight of the shoot, stem diameter at the root collar, the ratio of the top height to stem diameter (sturdiness ratio), and the presence of seedling terminal buds and so on.

(b) The characteristics of the seedling root system. This can be estimated by the root length, the number of lateral roots, and root weight etc.

(c) The ratio of shoot weight and root weight and the Dickson quality index.

Physiological attributes of the seedling include root growth potential (RGP), root membrane function, bud dormancy, frost hardiness of shoot, frost hardiness of root, resistance to desiccation, rough handling and cold storage, and sensitivity to insecticide.

Considering the above features, the optimum seedling should be healthy and vigorous, and meet the following conditions:

(a) The stem is strong and perfectly woody.

(b) The seedling does not have more than one leader and is not forked.

(c) The main root is straight and long enough, and there are enough lateral roots in the root system.

(d) The seedling has a sufficient amount of needles.

(e) The bark has no detrimental defect or the other wounds. And it has no plant disease, pests or pest eggs.

(f) The leader has a healthy terminal bud.

According to these conditions, the nursery operator evaluates and classifies the seedlings. The classification is mainly based on the measurement of morphological characteristics, avoiding the man-made error. It does not mean that the physiological characteristics are not important and

simply, the morphological characteristics are less susceptive to man-made errors.

Methods of ASC

The automatic grading method has been studied since the 1960s. Two measurement methods were used in the automatic grading. One is photoelectric measuring, and the other is computer vision measuring.

Photoelectric measuring period

Manual grading is loaded with trivial details to measure seedlings by mechanical measures. The requirement for improving the measuring methods has long been recognized. Photoelectric measurement and electromagnetic measurement have been developed and applied into seedling grading field successfully. The photoelectric and electromagnetic devices were developed to automatically measure some morphological characteristics of seedling. It was the start of the automatic grading of seedlings, though it could not replace the manual grading method completely.

The earliest device developed to measure the morphological characteristics of seedlings was designed by Mollison and reported in 1968. The device, called a Rhizometer, measured the total area of a root system. Although the device only measured one characteristic of the seedling, it proved the feasibility of the automatic measurement of the seedling characteristics and showed a new direction for the researches in the seedling-grading field.

A digital system for measuring and recording the stem diameter, shoot height, root area index (silhouette area), and sample number of seedling was described by Buckley *et al.* (1978). The system used potentiometric transducers and a linear 1 024 elements photodetector. Although the results of the measurements were accurate, the apparatus was too slow to grade large quantities of seedlings at production line rates.

An automatic grading machine of seedling was commercially tested in 1981. The machine measured the seedlings' diameter and height of shoot, and then classified them into three grades. Productivity was less than 1 000 seedlings/h, two to three times slower than manual grading (Lawyer 1981).

In 1982, to grade pine seedlings, Ardanlan and Hassan (1982) designed two sorting devices–one using an optical detector and the other using a linear displacement potentiometer. The detection rate was increased and the detection result was more accurate. However it was still slower than the manual sorting method.

All above-mentioned studies were typical studies on the photoelectric measuring method of seedlings. They could measure some morphological characteristics of seedlings automatically, but the measuring rate cannot meet the requirements of production, nor can they take the place of the manual grading method. They, therefore, must be combined with the manual measurement to grade seedlings. Although the automated measurement methods are too slow to meet today's production needs, they provide groundwork for further research.

Computer vision measuring period

As the electronics and computer technique, especially the computer vision technique developing, the researches in automation of the seedling grading made great progresses. Digital image processing has been successfully implemented in many inspection processes. It has demonstrated high accuracy and output. Computer vision inspection appears to be an ideal tool for resolving the seedling-grading problem. The system uses cameras to acquire images of seedlings. The images are processed and analyzed by computer. The features of seedling are recognized and the morphological characteristics are measured by image processing and pattern recognition. The seedlings are then automatically evaluated and classified according to their measurements.

The earliest study using computer vision for seedling grading was reported by Ringey and Kranzler (1988). A computer vision system equipped with a machine vision computer, cameras, lenses, lights, and a conveyor belt was described in their papers. A computer vision algorithm for grading pine seedlings in real time had been developed. Single seedlings were inspected on a moving belt. Classification as acceptable or cull was based on a minimum criterion for stem diameter, shoot height, and projected root area. The classification takes approximately 0.25 s for one seeding, with an average classification error rate of 5.7%. Ringey and Kranzler (1989) proved the feasibility of using computer vision for seedling quality inspection. And in 1989, another study reported a computer vision system for measuring quality characteristics of nursery-grown pine seedlings. In laboratory tests, the performance of the system exceeded that of manual graders in terms of both accuracy and speed.

Ringey and Kranzler (1992) reported the line-scan inspection system of conifer seedlings. The system was based on line-scan imaging technology, and had a high resolution and inspection rate. A key aspect of the system was that could automatic recognize the root collar position of seedling. According to the root collar position, the root collar diameter, shoot height, and projected shoot and root areas were measured. Sturdiness ratio and shoot/root ratios were calculated. Grade was determined by comparing measured features with pre-defined set points. Seedlings were automatically classified.

In 1995, Ringey and Kranzler (1995) developed a PC-based computer vision system providing rapid measurement for morphological characteristics of bare-root seedling. The system used backlighting and a 2 048-pixel line-scan camera to acquire images with transverse resolutions as high as 0.05 mm for precise measurement of stem diameter. Individual seedling was inspected by the vision system in less than 0.25 s. The system provided a

user-friendly, menu-driven graphical interface. The system automatically located the root collar of seedling and measured stem diameter, shoot height, sturdiness ratio, root mass length, projected shoot and root area, shoot/root ratio, and percent of fine roots. Sample statistics were computed for each measured feature. The results of the measurements for each seedling may be stored for later analysis. Feature measurements may be compared with multi-class quality criteria to determine sample quality or to perform multi-class sorting. Statistical summary and classification reports may be printed to facilitate the communication of quality concerns with grading personnel. The system was tested at a commercial forest nursery.

In 1997, a new method was developed to solve the most challenging problems of computer vision seedling inspection. Ringey and Kranzler (1997) designed an automatic root collar locator to replace the typical heuristic algorithm. They summarized what they had done in seedling automatic grading and improved the algorithm for image processing and pattern recognition. Neural networks were developed to locate the seedling root collar and digital images were acquired by a computer vision inspection system. Precise morphological measurements and accurate grade assignment require reliable identification of the root collar location of a seedling. The big variability of seedling morphology makes automatic root collar location difficult. Simple feed –forward NN's trained with the back-propagation algorithm were developed and two different network architectures were investigated and evaluated. The performance of several neural networks were superior to that of the heuristic algorithm.

Suh and Miles (1988) used a computer vision system installed in a microcomputer networked to a workstation to make laboratory measurements of stem diameter, shoot height, and shoot and root projected areas of pine seedlings. They used the zoom feature of the video camera to get different images of the total collar area of the entire seedling, and they used makers and template techniques to locate seedling root collars and terminal buds.

In 1992, Hassan *et al.* (1992) used a machine vision system with 0.5 mm spatial resolution to acquire images. And the root collar diameter, root projected area, and shoot height were measured through image processing. Hassan showed that a machine vision system was useful as a tool for morphological measurements and might have application in future automation of nursery sorting practice.

Kutz *et al.* described two-camera and three-camera computer vision systems developed for seedling quality control and researched measurement applications. The two and three camera systems provided inspection rates of 5.8 s and 15.8 s per seedling. Both systems had 0.1 mm resolution for diameter measurement. In addition, Lebowitz, Ruzhitsky and Ling, Howarth and Stanwood, Gasvoda *et al.* also studied the automatic seedling grading (Gasvoda 1994; Wilhot 1994; Howarth 1992; Lebowitz 1988; Ruzhitsky 1992).

The studies on the system of automatic seedling grading, extraction of morphological features of seedling, and the algorithm of seedling image processing were reported by Bai Jingfeng *et al.* (1998, 2000, 2001). An automatic seedling grading system based on the computer vision was designed. The system uses eight morphological characteristics, such as root collar diameter, shoot height, root length, sturdiness ratio and so on, as the pattern features of seedling grading. The characteristics are measured by image processing. A fuzzy neural network (FNN) is constructed to grade seedling. Using the pattern features as inputs, the FNN grades the seedlings into three classes after it is trained by the samples.

All this researches proved the feasibility of the application of computer vision in the seedling-grading field. As the technologies of computers, vision theory, image processing, and artificial intelligence develop, the application of computer vision in seedling grading will improve. In the future, the computer vision system will be the quickest and most accurate method for the automatic grading of seedlings.

Prospect of automatic seedling grading

Although the automatic method of seeding grading has improved, some problems still need to be solved and some deficiencies need to be improved.

Criterion of seedling grading

The quality of a seedling is determined by the measurement of its characteristics. The seedling is then assessed according to its morphological characteristics. This does not mean that the other characteristics are not important to the seedling quality, just that morphological characteristics are easily measured relative to its physiological features. In the research of automatic seedling grading, more and more features tend to be measured. An overall quality evaluation would be achieved by appending some physiological characteristics to the morphological characteristics as the grading features. Furthermore, now the morphological characteristics are being measured by a 2D image processing. Because the morphological features of seedling are complex, the simple 2D projection of seedling cannot reflect the full impress of a seedling. For example, the measurements on a projected area are different for different acquiring direction. Compared with 2D features, the 3D features would be more favorable for the evaluation of the seedling quality.

Measurement of seedling characteristics

As the characteristics to be measured changing, the measuring method needs to be improved too. The new characteristics could be measured by color image processing and 3D image processing. The color vision and 3D vision, which are more like human vision, have been applied to the detection field successfully.

More information can be acquired using color imaging.

Researches for the application of color image processing in apple grading were reported in 2000. In the paper, a real-time apple color grading system based on genetic neural network was described. The color features of an apple were acquired by image processing, and the apples were graded by a genetic neural network according to their color features (Li 2000). The color image processing has been applied to sort wheat grain, grade the peach, and classify potato, peanut, and tobacco leafs and so on (Miller 1989; Neuman 1989; Tao 1995). And a great achievement has been gotten in the study of the algorithm of 3D image processing (Guo 1994; Liu 1999; Schubert Erhard 1994; Zhou 1999). All this researches provide a theory basis for the application of the techniques in the seedling grading operation.

Application in production

The automatic grading system has not been applied to production on a large scale. At present, the grading rate cannot meet the requirement of production line. The grading results of the systems are not satisfactory and the grading efficiency still needs to be improved. Since the feasibility has been proven, the problem is how to construct a precise, efficient system to satisfy production. This is an important task for future research.

Conclusions

As the automation technique and computer vision developed rapidly, the automation of seedlings grading operation was studied. In the earliest research projects, only one or two characteristics of seedling were measured automatically. As the digital image processing was successfully implemented in many inspection processes, computer vision inspection appears to be an ideal tool for seedlings grading. The grading system based on the computer vision has been studied. The feasibility of automatic seedling grading by computer vision has been proved by these studies although the grading system has not been applied into production in a large scale. To improve the performance of the system, the grading criterion needs to be modified. Some 3D morphological characteristics, such as the volumes of root and shoot and some physiological characteristics, would be acceptable as a new grading criterion. The application of color image processing and 3D image processing in seedling inspection would be an important task to complete the measurement of the characteristics in the new criterion. The study on the seedling grading system based on the color image processing and 3D image processing would be a promising subject for further research.

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